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CURRENT RESEARCH ON QUARANTINE ASPECTS OF THE ALFALFA WEEVIL PROBLEM

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Introduction

The status of the alfalfa wevil problem with particular reference to quarantines was discussed by P. N. Annand before the Central Plant Board at its meeting a year ago and was subsequently published. [2] That review centered attention upon needed research, which the alfalfa weevil laboratory of the Bureau of Entomology and Plant Quarantine has since undertaken.

Last August a project was undertaken to determine the facts relative to contamination of baled alfalfa hay, native grass hay, and cereal straw by the alfalfa weevil and thereby to learn whether and under what conditions baled hay might be shipped out of weevil-infested regions without increasing the possibility of transporting the insect into uninfested territory. To give the project a broad and practical foundation, inquiry will be made into various practices and conditions affecting the hay business in different parts of the weevil-infested territory. Importance in this regard attaches to the relation of localities producing surplus hay to variations in regional abundance of the weevil and to the effect ,upon weevil contamination, of differing practices in regard to production, baling, storing, and time of shipment. This inquiry will also take into account the bearing of the weevil's biology upon the danger of weevil spread through shipment of baled hay and, finally, will relate these findings to other constant hazards of weevil dissemination.

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[1] The work on which this report is based was carried out, under the general direction of the senior author, by R. W. Bunn, assisted successively by H. F. Cline and W. E. Peay, and intermittently by W. C. McDuffie and J. C. Hamlin.

[2] Annand, P. N. Present status of the alfalfa weevil problem with particular reference to quarantines. U. S. Dept. Agr., Bur. Ent. and Pl. Quar., E-378 (mimeographed), April 1936.

The immediate attack has been directed toward determining the longevity of weevils in baled alfalfa hay and the frequency with which they occur naturally in it. All work to date has been performed in Salt Lake Valley, Utah, which is a heavily infested area. Consequently, the results relating to natural occurrence in baled hay have no reference to conditions of infestation that may exist in those portions of the weevil-infested territory where the insect occurs more sparingly. Notwithstanding the limitations within which present results must be construed, it is considered desirable to make them available at this time in order that Bureau workers may benefit from suggestions of interested persons for the future guidance of the investigation.

Development of Methods

At the very outset we were confronted with the necessity of developing a technique making possible rapid examination of large quantities of hay in order that a sufficient number of bales might be included to provide trustworthy results. Looking for weevils in hay is on the same plane with searching for the proverbial "needle in a haystack", and earlier experience had demonstrated the impracticability of hand-collecting weevils by picking over the hay bit by bit, or even by shaking out the chaff and examining all of this by careful visual methods. Such examination requires ,on the average, one day for a man to examine three-fourths of a cubic foot of chaff and, at this rate, from two weeks to a month would be required to examine a single bale of hay. Moreover, even the most competent men will occasionally miss a weevil. This problem has been solved by following the suggestion of Dr. Annand that the Berlese funnel be used to drive living weevils from hay chaff, after having removed the stems and very fine particles by means of a motor-driven shaker.

The shaker used (figs. 1 and 2) was constructed by R. W. Bunn, following the one devised by Campbell and Stone. [3] It is provided with two screen-bottom trays, the upper screen having 2½ meshes and the lower one 16 meshes per inch. In the upper tray the flakes of baled hay are thoroughly torn apart, one at a time, and the loosened hay is churned repeatedly. These manual operations, combined with the reciprocal action of the shaker, effect the desired separation. The stems are caught on the upper tray and are discarded. The very fine particles pass through the fine screen of the lower tray, leaving the hay chaff, together with any weevils, in the lower tray. The shaker operation removes approximately two-thirds of the volume that was in the bale originally.

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[3] Campbell, R. E., and Stone, M. W. Soil Sifters for Subterranean Insects. U. S. Dept. Agr., Bur. Ent. and Pl. Quar., ET-49 (multigraphed), May 1935.

Considerable preliminary study was required to determine what type of funnel would be most suitable for extracting weevils from hay chaff. Because of its poor heat-conducting qualities, the chaff had to be spread out in a fairly thin layer, with the heat applied from above. Consequently the funnels used are large and shallow (figs. 3 and 4). These funnels were constructed by W. C. McDuffie, following the general plan used by L. D. Christensen [4] They are 53 inches high, and the upper ,cylindrical part has a diameter of 47 inches. The chaff is spread on a tray, made of 4-mesh hardware cloth, which rests upon brackets flush with the upper edge of the cone. The inner surface of the cover is fitted with 13 electric globes so that the heat and light are directly above the chaff. As the heat within this tray increases, the weevils crawl deeper into the loose chaff until they fall through the screen meshes onto the sloping sides of the funnel and thence into a catch bottle placed at the bottom of the cone.

Careful tests of these funnels, extending over several weeks, were necessary to work out, empirically ,the proper thickness of the chaff layer and the current consumption or amount of heat required to drive out all living weevils within a reasonable time. Thermoregulators were used initially but they were found to be unnecessary since, with proper wattage, the input of heat came into balance with losses from radiation. It was found that complete extraction of normally active weevils introduced with chaff could be obtained by any one of three operating conditions, shown in table 1. Detailed results of the experiments are presented in table 2.

Table 1. -- Successful operating conditions in Berlese funnel established experimentally ,Salt Lake City, Utah, 1936.

Electric light wattage	Charge of chaff: Volume (cu. ft.)	Charge of chaff: Average depth without compacting (inches)	Time (minutes)
1,000	0.5	0.75	30
1,000	1.0	1.25	90
1,300	1.5	1.75	123

The 90-minute exposure with 1,000 watts [5] current consumption and 1 cubic foot of chaff was adopted as the standard. Chaff treated under these conditions was found to have a mass temperature of 120° F. at the end

[4] Christensen, L. D. A. Berlese funnel for collecting smaller soil animals, U. S. Dept. Agr., Bur. Ent. and Pl. Quar., ET-81 (multigraphed), May 1936.

[5] Slightly lower wattage was required in the two newer funnels, which were fitted with wood tops and so radiated less heat than the original, metal-top funnel in which extraction tests were made.

Table 2. - Summary of experiments with 4-foot-diameter Berlese funnel, Salt Lake City, Utah, September 1936.

Experiment No.	Heating unit (watts)	Charge of chaff (cu. ft.)	Weevils: Number	Weevils: Condition	Recovery: Percent	Recovery: Time (mins.)	Final temp. (°F.)
1	650	0.5	100	Subjected to baling	100	30	170.6
2	650	.5	100	do.	97	40	--
3	650	.5	100	50 normally, 50 subnormally active	60	35	163.4
4	650	.5	--	do.	61	46	--
5	650	.5	100	do.	76	41	168.8
6	650	.5	100	Normally active	99	47	171.5
7	650	.5	100	do.	95	41	169.7
8	650	.5	100	do.	96	45	171.1
9	650	.5	100	do.	97	53	168.8
10	650	.5	100	do.	100	39(a)	167.0
11	525	.5	50	do.	98	152(b)	172.4
12	1000	.5	50	do.	100	30	185.0
13	1,000	1.0	100	do.	100	113	194.0
14	1,000	1.0	50	do.	100	90	215.6
15	1,300	1.5	100	do.	100	123	--

(a) Weevils put on chaff in hopper 31 minutes before lights were turned on to allow time for them to crawl into chaff.

(b) 100 percent recovery when catch bottle was removed the following morning, 15 hours and 50 minutes later.

of the exposure. The 90-minute interval yielded the greatest efficiency when one man was operating three funnels and one shaker. With this equipment one man can examine from 1 to $1\frac{1}{2}$ bales of hay daily.

Experimental Determination of Weevil Longevity in Baled Alfalfa Hay

An experiment was designed to determine the longevity of weevils, artificially introduced into hay, to serve as a check upon natural occurrence of weevils in baled hay. On September 3, 1936, 2,000 living weevils were placed in each of seven bales of alfalfa hay that was being put up from third-cutting haycocks. The weevils for a given bale were divided into 10 lots of 200 each and were sprinkled into the hay as it was being compressed, so they would be distributed throughout the bale. The weevils used had recently been collected from the bottoms of haystacks, mostly of second-cutting hay.

These bales, together with any loose chaff remaining on the floor of the baling chamber, were wrapped in canvas as soon as baled and transported to the laboratory, where their exteriors were swept free of loose material. Six bales were then put into individual sheet-metal storage cabinets so constructed that any weevils leaving the bales would collect in oil-pan traps for counting (fig. 5). The cabinets were located in the Salt Lake City Federal Building basement, where the air temperature was remarkably even and averaged 70° F.

The other bale had its wires cut shortly after arival at the laboratory in order that the percentage killed by compression might be distinguished from any mortality due to confinement in stored bales. Examination results were as follows: 38 weevils, 27 living and 11 dead, were obtained from the loose chaff swept from the exterior of the bale before it was opened. The shaker-funnel treatment yielded 1,611 living weevils. After removal of each charge of chaff from the funnels, one-eighth of it was examined by careful visual methods for dead weevils, and on this basis it is estimated that there were 216 dead weevils in the bale. These operations accounted for a total of 1,865 weevils, of which an unknown, but doubtless small, fraction occurred naturally in the hay when it was baled. These figures place the compression kill at only 11.82 percent.

Results of the entire series, opened at intervals of from zero to 153 days after baling, are summarized in table 3. As shown in column 3, from 38 to 199 weevils, or roughly from 2 to 10 percent of those placed in the bales, were swept from their surfaces shortly after baling. The fifth column shows that from 7.80 to 22.74 percent of the recovered weevils crawled out of the bales and dropped into the catch pans. Of these an average of 57 percent appeared during the first 10 days of storage, 71 percent in 20 days, and 82 percent in 30 days. The last weevil was caught 109 days after baling, but this does not necessarily mean that this individual had just emerged from the bale, since it may have remained on the bale surface for some time before dropping into the catch pan. Small numbers of weevils crawled from the interior of bales and died on bale surfaces without dropping into catch pans, these numbers ranging from 6 to 37 weevils per bale and averaging 21.8.

Table 3.--Summary of results from experimentally stored bales of alfalfa hay.

Bale No.	Storage period (days)	Number of weevils brushed from exterior before bale was set in storage cabinet	Total number of weevils recovered from bale during and after storage period	Proportion that crawled out during storage period (percent)	Proportion surviving storage period in bale (percent)
1	0	38	1,827	---	88.18
2	10	84	1,628	7.80	64.82
3	31	103	1,327	11.76	25.53
4	61	60	1,816	8.92	0.73
5	91	199	1,118	21.11	0.45
6	123	161	1,082	22.74	0
7	153	73	1,081	13.88	0

The sixth column of table 3 shows that the initial survival of the baling process was 88.18 percent, declining to 25.53 percent at the end of 31 days. After 61 days 0.73 of 1 percent survived, and this was not appreciably reduced at the end of 91 days, when 0.45 of 1 percent remained alive. No weevil survived after 123 days' storage and none was alive in the final bale, examined 153 days after the hay was baled. The survival curve is shown in figure 6. A check lot of weevils of the same origin and history, except that they had not been through the baling process, was kept with dampened chaff near the storage cabinets. These weevils, too, died off, but not so rapidly as those in the bales, for whereas the survival in bales had dwindled to less than 1 percent at the end of 2 months, approximately this same percentage survived in the check after 5 months.

Weevils recovered from bales dismantled after intervals of zero, 10, and 31 days' storage were placed with dampened chaff and kept at approximately 70° F. to learn how long they would live. From 50 to 72 percent died within 10 days, the mortality being proportioned to the storage period. From 65 to 79 percent were dead after a month, and thereafter the decline was quite gradual until over 99 percent were dead after 5 months.

Natural Occurrence of Weevils in Baled Alfalfa Hay

Supplementary studies were undertaken to determine, from farm-collected samples, the frequency of occurrence of living weevils in alfalfa hay of the three normal cuttings, baled both from cocks in the field and from haystacks; also how long such contamination endures, and whether the contamination is contained chiefly within the bales or located on their surfaces. Three bales were taken from each lot of hay studied, the pile of bales being sampled to give the best distribution possible with three

bales. These bales were put into individual canvas bags immediately after being taken from the bale pile. At the laboratory the bale was removed from the bag and its surface swept with a broom to dislodge any weevils that might be merely resting on the surface. The bale was then returned to the canvas bag and placed beside the shaker, where the baling wires were broken. It then passed through the shaker-funnel process already described. Seventy-two [6] bales of alfalfa hay, totaling $3\frac{1}{2}$ tons, have been examined since October 20, 1936.

Thirty-six [6] bales were examined between October 20, 1936, and January 9, 1937 to determine the relative infestation of cock-baled and stack-baled hay from each of the three normal cuttings. These bales came from 12 farms in the Salt Lake Valley, Utah. The bales were stored in the open or in barns, sometimes in close proximity to loose hay of the 1936 harvests. The results are summarized in table 4.

Table 4. - Summary of results from examinations of 36 bales of alfalfa hay, October 20, 1936. to January 9, 1937, Salt Lake Valley, Utah.

Baled from	Harvest	Days in stack (Approx.)	Days in bale (average)	Bales examined		Weevils per bale	
				Number	Percent Infested	Range	Average
	1st	165	14	6	100	1-71	20.0
Stack	2nd	101	8	3	100	40-47	43.7
	3rd	15	31	3	100	14-47	33.3
Tot. or Avg.		111	17	12	100	1-71	29.3
	1st	0	186	12	33	0-2	0.5
Cock	2nd	0	115	6	50	0-3	1.2
	3rd	0	105	3	0	---	0
Tot. or Avg.		0	154	21	33	0-3	0.6
"Pile"	2nd	14	90	3	100	5-20	10.7

The averages (table 4), which do not distinguish between different cuttings, show that 100 percent of the bales put up from haystacks were infested as against 33 percent of those baled from cocks in the field. Moreover, weevils were 49 times as numerous in stack-baled as in cock-baled hay, the respective averages being 29.3 weevils and 0.6 weevil per bale. This differential infestation is borne out by the figures for

[6] Exclusive of one bale from an exceptional fourth cutting.

each crop. Thus, first-cutting hay averaged 20.0 weevils per bale of hay from stacks as contrasted with 0.5 weevil per bale from haycocks. Similarly, second-cutting hay had respective averages of 43.7 and 1.2, while third-cutting hay showed comparable averages of 33.3 and 0.

It is noteworthy that weevils were most numerous in second-cutting hay, whether stack-baled or field-baled. This condition doubtless reflects the fact, determined in recent ecological studies in Salt Lake Valley, that the new generation of adult weevils is produced in two divisions, one appearing about June 15 and the other in the latter half of July. Both divisions of new-generation adults are present when second-crop hay is baled or stacked.

Data on one exceptional lot of hay have been appended to table 4. Original inquiry indicated that it had been baled in the field, and the results were originally tabulated among lots baled from haycocks. However, its high level of infestation was entirely out of line with those of other lots baled from cocks and suggested that it might actually have been baled from a haystack. Further investigation revealed that it was an anomalous lot of hay, the haycocks having been put into a loose pile and left in the field for about 2 weeks before being baled. All three bales were infested, and the average of 10.7 weevils per bale was intermediate between the averages of stack-baled and cock-baled lots.

The above results very clearly indicate that weevil contamination continued longer and at a higher level in hay that was first stacked and then baled in fall or early in winter than in hay baled directly from haycocks. The reason for this difference is not known.

The loose material swept from the surfaces of bales prior to shaking and funneling yielded living weevils from 7 of the 22 bales that were infested. In five instances only a single weevil was thus found, two in another instance, and in one exceptional case six living weevils were recovered from a bale [7] that had been stored in a barn in close proximity to loose hay of the first and second cuttings in 1936. These findings indicate that considerable importance attaches to conditions of storage.

From January 12 to 27, 1937, five lots of baled hay were resampled to learn what changes, if any, had occurred in the weevil infestations existing before Christmas. The data, summarized in table 5, show that the two lots of stack-baled hay continued to be 100 percent infested, but the averages of 33.3 and 43.7 weevils per bale which existed within a month after baling had declined to 7.3 and 4.7 weevils per bale, respectively, in 101 and 71 days after baling. In bales originating from hay "piled" in the field for a fortnight the percentage infested declined from 100 to 33 as the interval after baling lengthened from 111 to 169 days. The average infestation also declined from 10.7 weevils to 0.3 weevil per bale, or one weevil to the three bales examined. This bale was one of a lot stored in a barn with loose hay. The two lots of cock-baled hay were originally sampled 109 and 188 days after baling, and again after

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[7] It was also one from the anomalous lot of hay just mentioned.

184 and 225 days. Between examinations the infestation in one lot decreased from 67 percent infested and an average of 1.3 weevils per bale to zero infestation, and in the other it decreased from 67 to 33 percent infested and an average of 0.3 weevil per bale. These three lots of hay, comprising nine bales yielded only two weevils after having been baled in excess of 169 days. However, attention is directed to the fact that the two weevils came from lots of baled hay which had been stored with loose hay in barns, and in one instance the weevil was recovered from the exterior of the bale.

Table 5.-- Resampling data on five lots of baled alfalfa hay, Salt Lake Valley, Utah, 1936-1937. (3 bales in each sampling)

		First examination, fall and early winter, 1936			Second examination, January 1937		
Baled from	Harvest	Average number of days in bale	Percent of bales infested	Average number of weevils	Average number of days in bale	Percent of bales infested	Average number of weevils
Stack	3rd	31	100	33.3	101	100	7.3
Stack	2nd	8	100	43.7	71	100	4.7
"Pile"	2nd	111	100	10.7	169	33	0.3 (a)
Cock	2nd	109	67	1.3	184	0	0
Cock	1st	188	67	1.0	225	33	0.3(b)

(a) Bale stored in a barn with loose hay.

(b) This weevil was swept from the exterior of the bale. The bales were stored in a barn with loose hay.

In order to learn whether hay baled from stacks in midwinter would be free of living weevils, four lots of bales were examined between January 29 and February 11, 1937. Moreover, the three bales of each lot were selected at the time of baling to represent top, middle, and bottom locations in the haystacks. The results, shown in table 6, demonstrate that small numbers of weevils may live 7½ months in haystacks [8] and then survive the mechanical process of baling. This result is particularly informative in view of the exceptionally low temperatures experienced in Salt Lake Valley this winter (1936-37). Weevils in these haystacks were too few to supply worth-while information on distribution within the stacks, but the results do show that a few weevils are to be found in the middle and bottom parts of haystacks after extended periods in the stacks.

[8] Christensen (unpublished notes) found 1.9 percent of the weevils alive in a sample of hay taken from a first-cutting haystack on January 31, 1928, almost 8 months after it was stacked. He also found 8.1 percent living weevils in "the very center" of a second-cutting haystack on January 25, 1928, and 8.3 percent alive in about the center of a third-cutting stack on February 9, 1928. On March 26, 1928, he found 11.1 percent living weevils in a sample of hay taken about one-third of the way down from the top of a third-crop stack.

Table 6. - Data from examinations of hay cut and stacked in the midsummer of 1936 and baled in the following midwinter, Salt Lake Valley, Utah

Harvest	Hay cut (date)	Days in stack (approx.)	Baled (date)	Examined (date)	Days in bale (average)	Weevils per bale (average)	Origin of weevils in haystack
2nd	Aug. 1	179	Feb. 3	Feb.8-9	6	0.3(a)	Bottom center
1st	June	222	Jan. 27	Jan.29-30	2	0	
1st	June 15	225	Jan. 30	Feb.1-3	3	0.7	Middle
1st	June 15	228	Feb. 4	Feb.10-11	7	0	

(a) This weevil was dead when found, but its condition showed that it had died very recently.

The latest examinations, made February 12-20, were of bales from second-cutting hay (table 7). One of these lots, which was baled from the stack at the end of September 1936, showed 33 percent infestation and averaged 0.3 weevil per bale after 137 days in the bale. The other two lots were baled from haycocks 192 to 198 days before examination. One lot was free of weevils while the other was 33 percent infested and averaged 1.0 weevil per bale.

Table 7. - Summarized results on nine bales of second-crop alfalfa hay examined February 12-20, 1937 Salt Lake Valley, Utah.

Baled from	Days in stack (approx.)	Days in bale (average)	Bales examined		Weevils per bale	
			Number	Percent infested	Range	Average
Stack	54	137	3	33	0-1	0.3
Cock	0	192	3	0	--	0
Cock	0	198	3	33	0-3	1.0

It may be noted that whereas longevity of weevils in storage-cabinet tests was less than 4 months, the studies of natural occurrence showed that, in bales put up from haycocks, contamination persisted beyond 6 months. This discrepancy may be due to higher temperature and perhaps lower humidity in the experimental installation, but it may represent the effect of secondary contamination. It is a common practice in Utah to store baled hay of one crop in barns containing loose or baled hay of other cuttings, or to store it in the open air next to haystacks or sheds, and in many cases to

cover the pile of bales with several inches of loose hay as protection against rain and snow. An effort was made to segregate this factor of secondary contamination by sweeping the surfaces of bales before opening and examining them, and some weevils were thus obtained as already mentioned. Nevertheless ,it is recognized that weevils may readily crawl into crevices of the bale where they cannot be removed by sweeping.

Let us reexamine the data on cock-baled hay of the first and second cuttings (table 4) in the light of storage conditions. Of the 12 first-cutting bales, 4 were contaminated. Two of these 4 originated in a lot of hay that stood in the field 2 days after baling and when piled in the barnyard was covered with 5 inches of loose, first-cutting hay; the other 2 infested bales came from a lot which was stored in a barn and then had bales of third-cutting hay piled upon it. Of the second-crop hay baled from haycocks, 3 of the 6 bales had weevils. Two of the infested bales came from a lotof hay stored in a barn with loose hay, and the other contaminated bale was one of a lot that had been first stored in a barn free of other hay but later was moved to another farm and stored near other baled hay. In some exceptional instances, however, bales were not contaminated with weevils although stored next to other hay. The importance of secondary contamination cannot be estimated from the present data but will receive close attention during the coming season.

Summarizing, these preliminary results indicate that, in a heavily infested region such as Salt Lake Valley in Utah, hay stacked in summer will not become free of infestation in time to take advantage of the winter market in uninfested territory. On the other hand, it appears that even with heavy infestation, hay of the first and possibly the second cutting, baled from the cocks immediately after harvest, and stored away from sources of secondary contamination, may possibly become weevil-free in time for midwinter shipment.

Biological Background of Hay Studies

In the foregoing discussion attention has been directed only to the number of living weevils in baled hay, and it is possible that the practical problem may satisfactorily be solved on this basis. Notwithstanding, the biology of the weevil in relation to harvest, baling, and storage may also vitally affect the possibility of spread of the pest.

Overwintering adult weevils are of little concern here since they are all dead by fall and therefore would not be a factor in winter shipment of hay. The new generation of adults is produced in two divisions, the one coinciding roughly with the first harvest in the first half of June and the other with the second harvest late in July. Ordinarily the second division is more numerous. A negligible number of adults may be produced during the third-crop growing period.

Now, most of the first-division weevils have just recently emerged when the first hay crop is cured and, consequently, have had little opportunity to feed and thereby to build up their food reserves when some of them are carried from the fields in bales of hay or into haystacks. When

second-crop hay is put up toward the end of July, there are in the field both recently emerged second-division weevils and first-division weevils which have had an opportunity to feed for about 6 weeks. Weevils in third-crop hay are partly those which have been in the field about 6 weeks and partly those which have been there 3 months.

Weevils carried into haystacks or imprisoned in bales of hay are without food and so must subsist on energy already stored in their bodies. Consequently new-generation adult weevils present in each of the three hay crops are believed to possess differential capabilities for survival. Those removed from the field with first-crop hay in mid-June are believed to have the smallest food reserves and so have the least likelihood of surviving prolonged starvation.

Finally, it must be stressed that the investigation has not progressed to the stage where any conclusion can be reached. Further results in Salt Lake Valley and in a sparsely infested region will be obtained during the coming year. Attention will also be directed to native grass hay and cereal straw.

Figure 1.-Detail of Shaker.

Figure 2.-Shaker Operation.

Figure 3.-Battery of Funnels.

Figure 4.-Inside of Funnel.

Figure 5.-Hay Storage Cabinets.

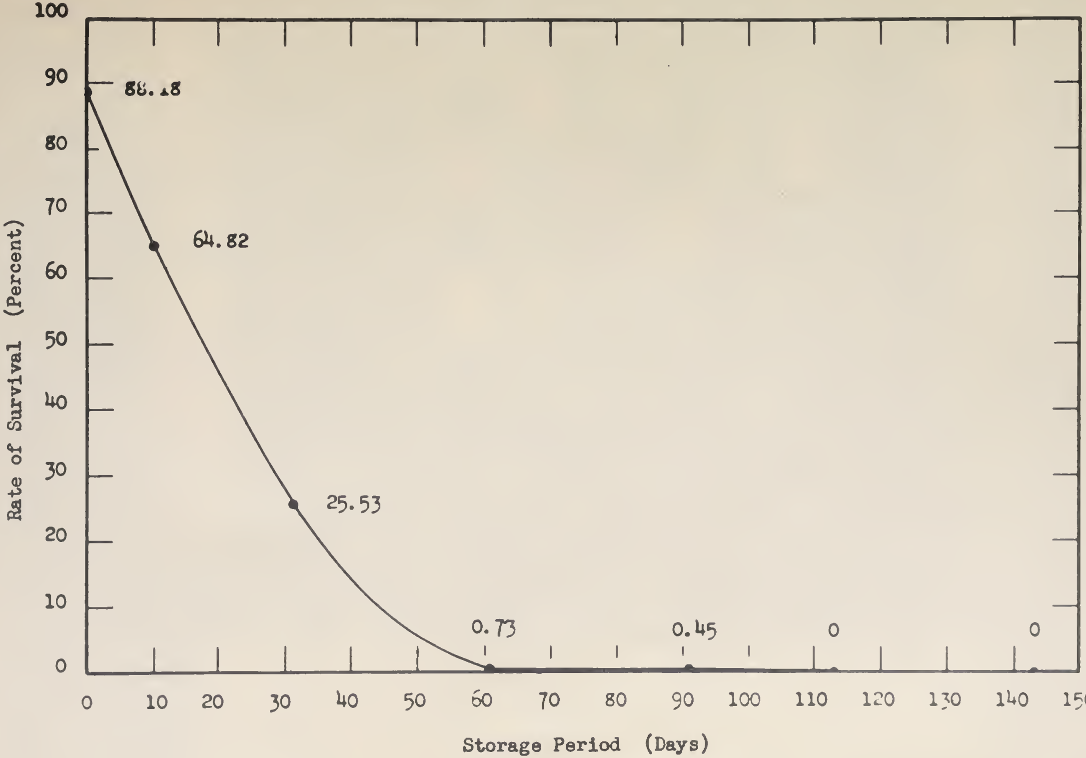

Figure 6.--Longevity of alfalfa weevil adults in baled alfalfa hay.